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AGRICULTURAL MEMORANDUM NO 432

The effect of group size on the Operative Temperature experienced by poultry - by C V Smith.

1. INTRODUCTION

The ability of social groups of animals to control or at least modify the thermal environment which they experience is well documented. The literature covers farm animals, for example pig litters, poultry flocks etc and extends to more esoteric groups such as bees and the musk ox herd (which in some circumstances generates its own personal 'cloud' of water vapour droplets and so modifies the radiative heat loss which the herd experiences).

The present note arises from a query on the interpretation of thermometer reading in poultry units where the birds are in battery cages and where the size of the bird groups is controlled by management rather than the birds themselves. The economic rationale behind the query lies in the fact that relationships exist which can convert environmental factors, such as temperature, to production factors such as growth rate, food intake or conversion rate. The cost of maintaining high ambient temperatures in poultry units can be more than offset by a saving in food costs at these high temperatures and one is concerned to identify the minimum of the curve, Cost of control vs. Amount of environmental control.

2. THE FORMULATION OF THE PROBLEM

Problems of the radiative and convective heat exchanges of animals inevitably in practice, involve considerations of the 'Shape' of the animal. Theoretical calculations can in fact only treat simple geometical shapes and configurations, and to arrive at working solutions, the animals have to be assumed to approximate to cylinders or spheres for example.

In the formulation of the problem presented, we consider an individual bird to be represented by a cylinder of diameter 6 inches and height 9 inches. The enclosure in which it is placed is again considered to be cylindrical and to be of diameter 18 inches and height 18 inches.

We consider the single bird at the centre of such an enclosure and then attempt to estimate the effect on the thermal environment of this bird, of successive addition of further birds (up to a total of 7 within the cage).

3. RADIATIVE HEAT LOSS CALCULATIONS

Let E = emissivity of the bird and enclosure
α = absorptivity of the bird and enclosure

Let A_b = vertical surface area of the cylinder to which our birds approximate
A_e = vertical surface are of the cylinder to which our enclosure approximates

FH1

Let $F_{b \to e}$ = Angle Factor for radiation passing from the central bird to the enclosure walls

Let $F_{e \to b}$ = Angle Factor for radiation passing from the enclosure walls to our central bird.

Let σ = Stefan-Boltzmann constant
Let T_b, T_e = absolute temperatures of bird surface and wall surface respectively

The net radiative loss (Q) of the central bird when alone in the cage may be written as

$$Q = E \propto F_{b \to e} A_b \sigma (T_b^4 - T_e^4)$$

and by the reciprocity thereon

$$F_{b \to e} A_b = F_{e \to b} A_e$$

The Angle Factor $F_{e \to b}$ can conveniently be determined from an Angle Factor catalogue (Sparrow and Cess, 1966) for the configuration specified.

Detailed calculations give $F_{e \to b} = .376$ for that part of the enclosure wall that extends up as far as the height of the birds and conversely, after making due allowance for the areas A_b, A_e, noting that we are dealing with approximate solutions and that an Angle Factor may not exceed the value, unity, we place $F_{b \to e} = 1$

Taking the simplest possible viewpoint, we assume that our central bird (cylinder) may be surrounded by 6 further birds (cylinders). Each bird that is added, in effect replaces part of the enclosure wall by a surface at the same radiative temperature as the central bird, whose radiative heat loss is now reduced. We assume that each bird added effectively reduces the radiating surface area of the enclosure, A_e, by a factor 1/6 and further reduces the Angle Factor $F_{e \to b}$ by a factor 1/6.

We may now draw up the following table

For the single bird, net radiative loss = Q
For the single bird + 1other, net radiative loss = (25/36) Q
For the single bird + 2 other, net radiative loss = (16/36) Q
For the single bird + 3 other net radiative loss = (9/36) Q
For the single bird +4others, net radiative loss = (4/36) Q
For the single bird + 5 others, net radiative loss = (1/36) Q
For the single bird + 6 others, net radiative loss = 0

We may determine the radiative temperature (T) of the environment of the central bird in each case. If in the initial case of the isolated, single bird we nominate the temperature of air and enclosure as 70°F, then the surface temperature of the bird will be around 79°F (Wilson, 1952). Inserting such numerical values as are necessary, we have the initial radiative heat loss as

$$Q = E \propto F_{e \rightarrow b} A_e \sigma ((460 + 79)^4 - (460 + 70)^4)$$

with the addition of 1 bird, the net radiative loss becomes

$$(25/36)\ E \propto F_{e \rightarrow b} A_e \sigma ((539)^4 - (530)^4)$$

$$= E \propto F_{e \rightarrow b} A_e \sigma ((539)^4 - T^4)$$

Carrying out the necessary arithmetic gives the following table

Single bird, radiative temperature of environment = 70°F
Single bird + 1 other, radiative temperature of environment = 72.8
Single bird + 2 other, radiative temperature of environment = 75.1
Single bird + 3 other, radiative temperature of environment = 76.8
Single bird + 4 other, radiative temperature of environment = 78.0
Single bird + 5 other, radiative temperature of environment = 78.8
Single bird + 6 other, radiative temperature of environment = 79

4. OPERATIVE TEMPERATURE

This parameter is discussed in Ag Mem 138 and essentially considers the combined effect of radiative and convective heat loss; 'Operative Temperature' in effect is a single quantity which weights radiative and convective exchanges according to their relative importance.

If the radiative loss in each of the combination of birds we have considered is written in the form

$$Q = Kr \quad (T_b - T)$$

and if the convective heat loss (Q') in each case is written in the form

$$Q' = Kc \quad (T_b - Ta)$$

where Ta = ambient air temperature.

then Ag Mem 138, or Schenck (1960) suggest numerical procedures to evaluate Kc.

We adopt a standard air velocity of 25 feet/minute in each case and find numerical values, in engineering units for

Kr = .92 Btu/hour
Kc = .385 Btu/hour

and $\frac{Kr}{Kr + Kc} = .71$

The Operative Temperature in each of the situations we have discussed is given in the following table.

Single	Operative Temperature of environment = 70°F
Single bird + 1 other,	Operative Temperature of environment = 71.6
Single bird + 2 other,	Operative Temperature of environment = 73.6
Single bird + 3 other,	Operative Temperature of environment = 74.8
Single bird + 4 other,	Operative Temperature of environment = 75.9
Single bird + 5 other,	Operative Temperature of environment = 76.2
Single bird + 6 other,	Operative Temperature of environment = 76.4

5. DISCUSSION AND A WORKING RULE OF THUMB

Obviously we have had to mould our problem in order to fit it into models that we can handle. Considerable approximations are involved and implicit in all the calculations is that we deal with a static situation, whereas in practice we have a fluid situation with our birds moving in a random fashion. Because of this it is suggested that a useful working rule might be that each bird after the first, that is added to a conventional size cage, provides the equivalent of a 1°deg F rise in ambient air temperature to the occupants of the cage. Such a figure would be in addition to the observed rise in air temperature associated with an increased metabolic heat input into the air as stock density is increased.

Meteorological Office
Cambridge
March 1972

Any comments should be directed to the author

6. REFERENCES

Smith C V Ag Mem 65 — A relationship between environment, comfort and productivity for poultry

Smith C V Ag Mem 138 — On the comparison of internal climates

Wilson W O, Hillerman J P, Edwards W H — 1952 — The relation of high environmental temperature to feather and skin temperature of laying pullets. Poultry Science Vol 31, No 5

Sparrow E M, Cess, R D — 1966 — Radiation Heat Transfer. Brooks Cole Publishing Co Belmont California

Schenk H — 1960 — Heat Transfer Engineering. Longmans, London